



JSF/F-35 Pollution Prevention Activities

**ESTCP/SERDP DoD Metal Finishing Workshop
22-23 May 2006
Washington DC**

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Agenda



- ***What is F-35/Joint Strike Fighter***
- ***Pollution Prevention (P2) Background***
- ***P2 Implemented System Solutions***
- ***P2 Solutions in Work***
- ***P2 Solutions Offering More Opportunities for Near Term F-35/ESTCP Partnerships***



What is Joint Strike Fighter ?



F-35A



**Conventional
Take Off Landing
(USAF)**

F-35B



**Short Take Off
Vertical Landing
(USMC and UK)**

F-35C



**Carrier Variant
(USN)**





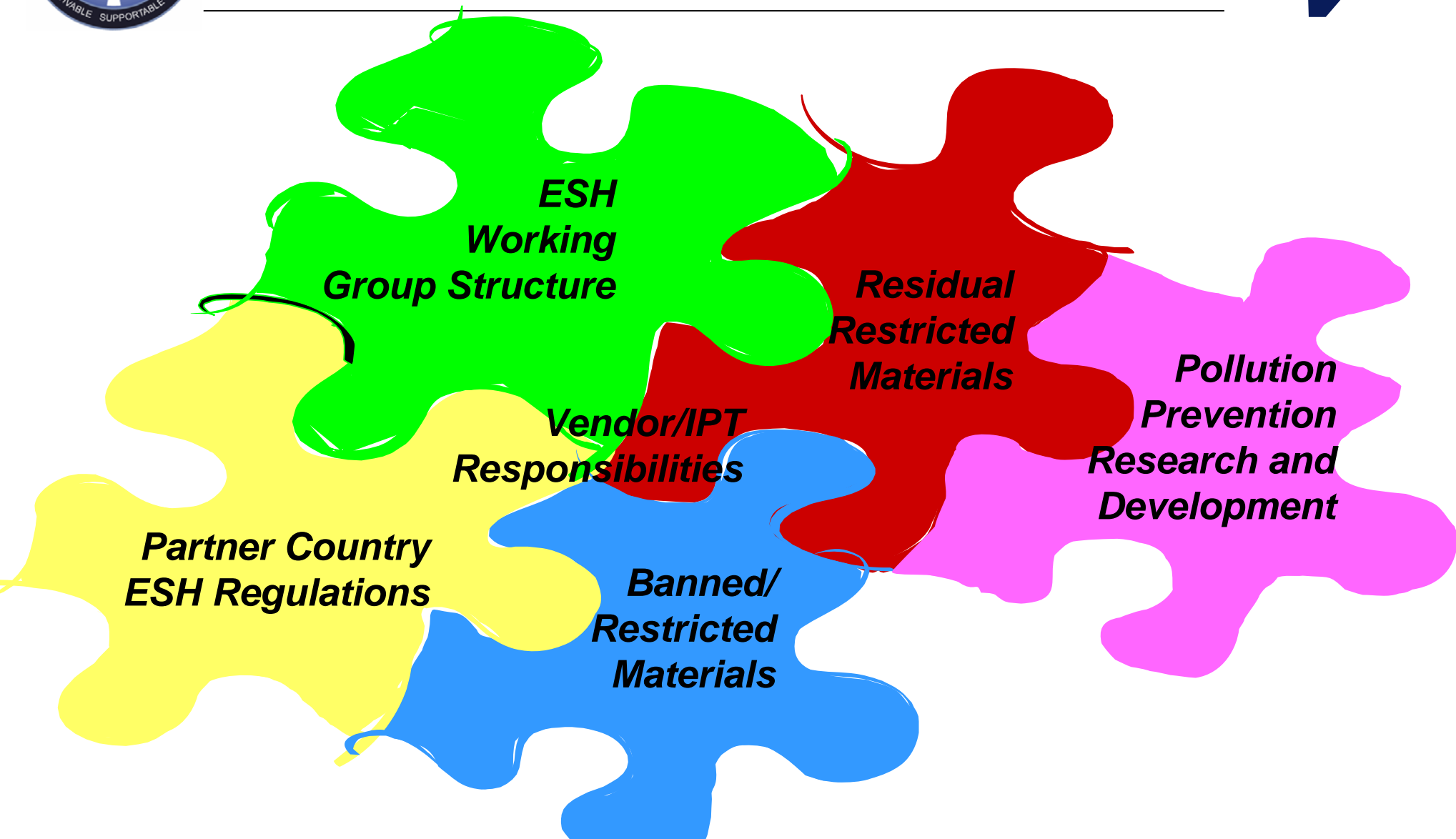
F-35 ESH Requirements



- **Contract Data Deliverable List CDRL-001
Air System Lifecycle Plan**
 - ***Hazardous Materials Reduction/Elimination Initiatives***
 - Identified and Controlled in Detailed Plan 2YZA00049
Hazardous Materials Management Plan
 - ***Demilitarization/Disposal Plans***
 - Demilitarization/Disposal Plan 2YZA00102
- **Contract Statement of Work Commits
LMAero/NGC/BAES to a Hazardous
Materials Management Plan and Formal
Working Group**



Hazardous Materials Management Plan (HMMP)



Dynamic, Results Oriented Document



The Continuing Sustainability Challenge and Interaction with Design for Environment (DfE)



- **LMAero Solved the Easy-To-Do Material/Process Substitutions on Previous Programs**
 - *Low Hanging Fruit*
 - *Typically Focused on Employee Exposure During Manufacturing*
- **Now the Challenge is to Find Material Substitutions That Reduce Life-Cycle Expense, i.e. Sustainability**
 - *Focus on Customer Maintainers Exposure During Operation, Maintenance, Depot Overhaul, Deactivation, Demilitarization, Disposal*
 - *Awareness of Hazmat Liability to Sub-tier Suppliers due to Current and Future Regulations*
 - *Reduce Life Cycle Cost Impact through Hazmat Minimization*
 - *This Results in the Design for Environment (DfE) Approach*

Identify the Goal and Force the Solution

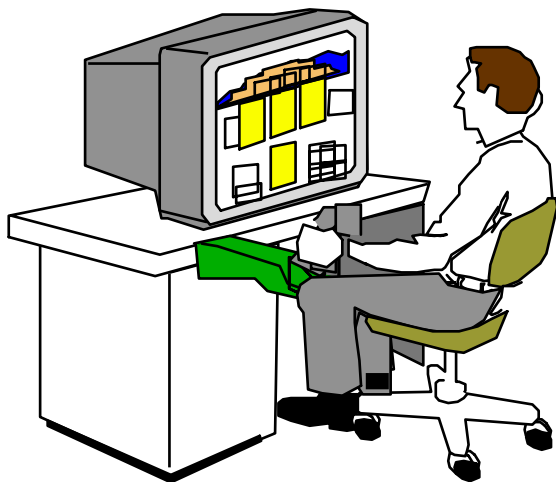


Hazardous Materials Control Approach – Controlled by HMMP and M&P

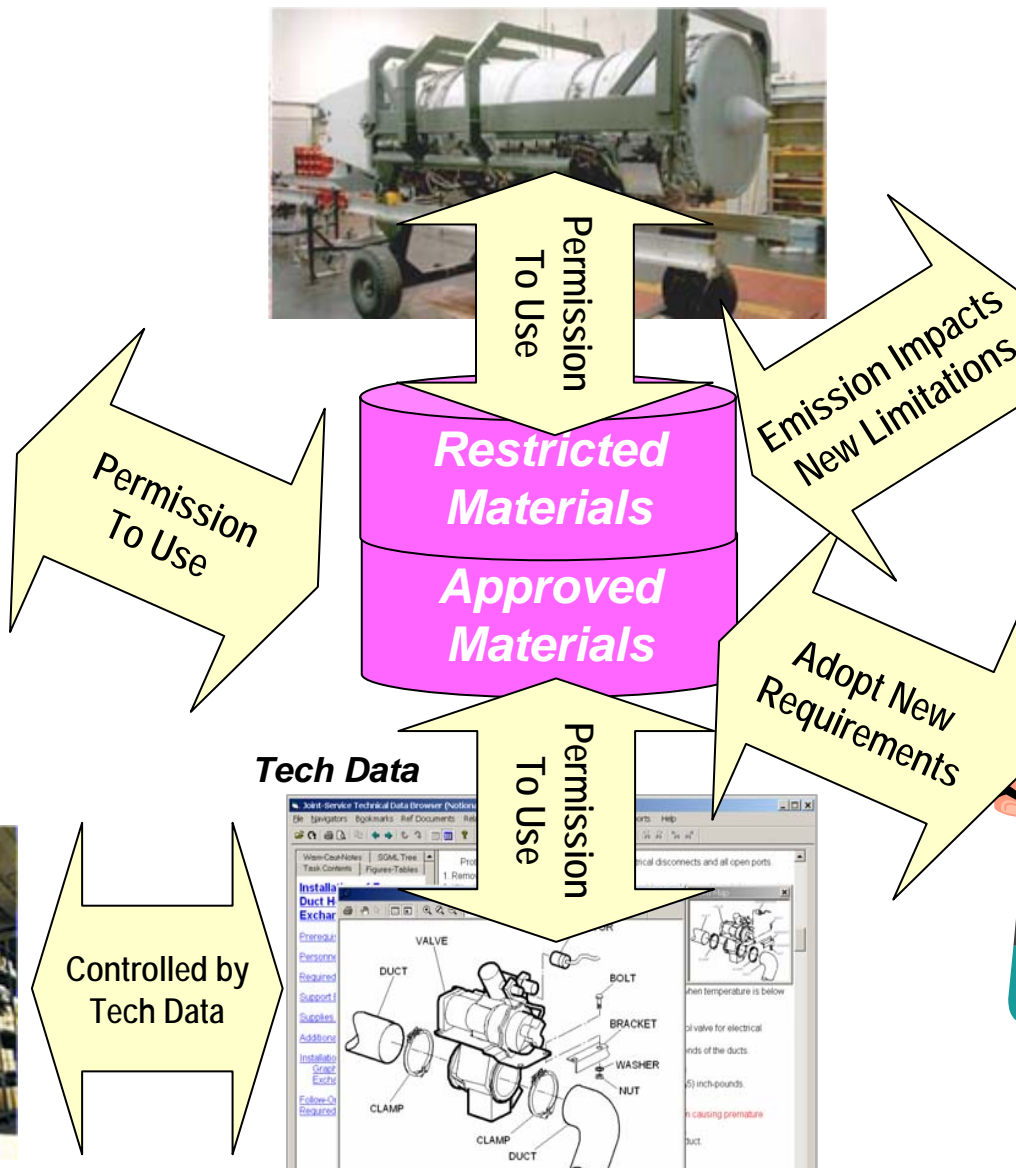


Support Equipment Design

**Airframe/
Subcontractor
Design**

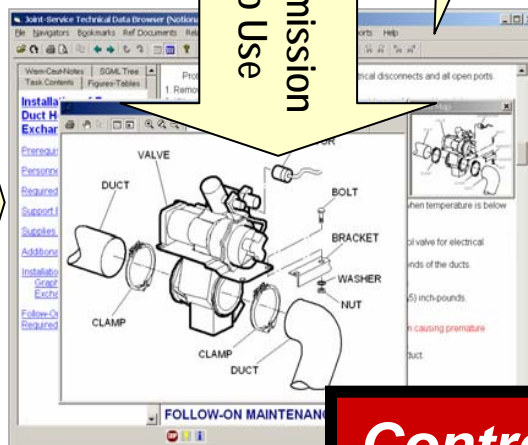


**NEPA/Conformity
Planning**



Supply

Tech Data

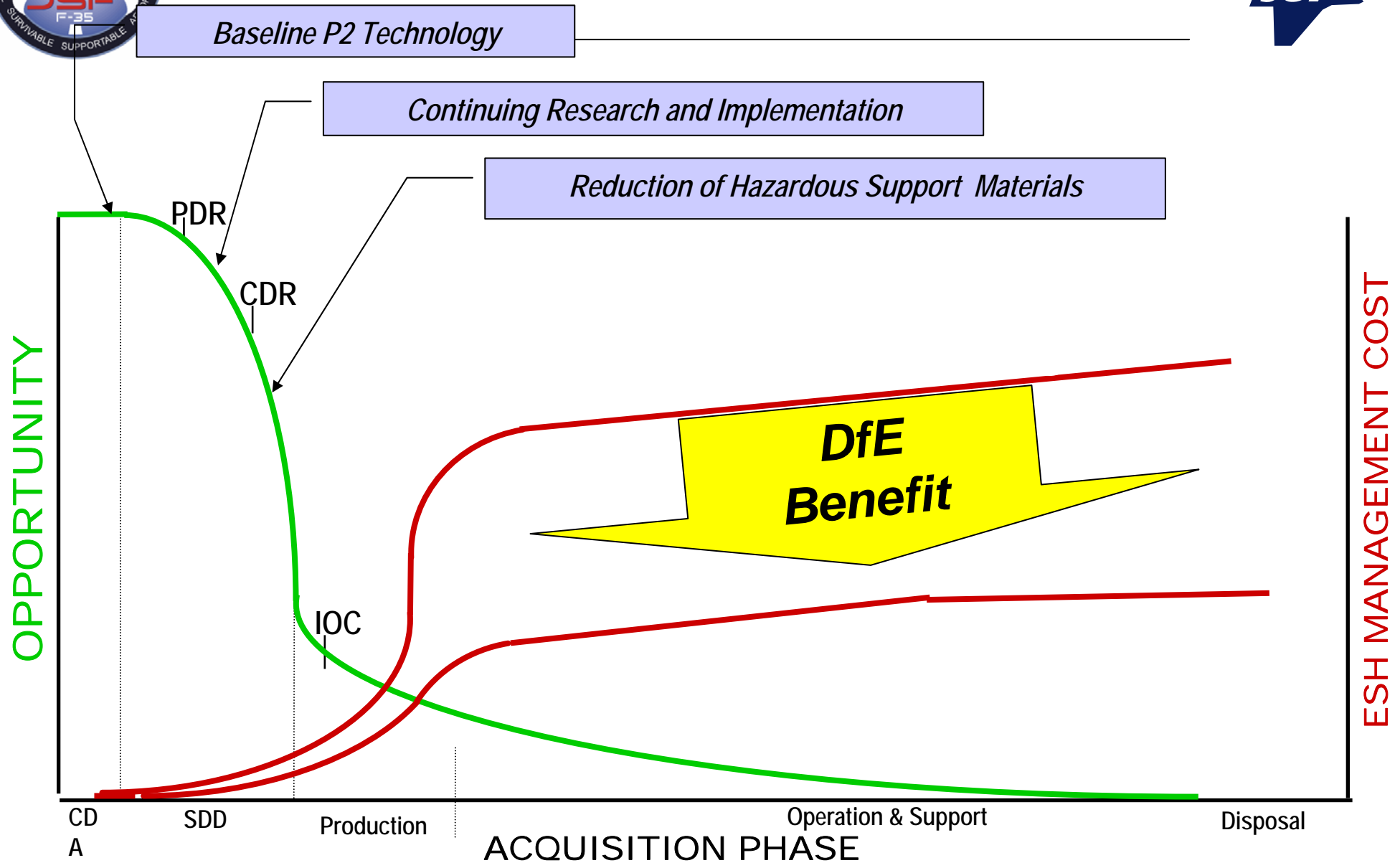


**Partner Country
Regulation Research**

Control Materials on Program



Pollution Prevention Insertion Opportunities



Reduce Life Cycle Costs Early in Program



Current F-35 Pollution Prevention Activities



**Implementing New Deft
Non-Chrome Primer for
Interior/Exterior Use**

**Testing Alumiplate™
to Replace
Nickel/Cadmium on
Metal/Composite
Electrical Connectors**

**Various Vendors
Testing New
Coatings and High
Strength SS**

**Implementing
HVOF WC-Co-Cr
and Alumiplate™
for Landing Gears**

**Cu-Be Bushing
Replacement Material**

**Aqueous
Nanocrystalline Co-P to
Replace EHC and TDC for
Actuation Systems**

Aggressively Investigating New Materials



System Solutions



System Changes and Improvements Implemented on F-35 With Demonstrable Pollution Prevention Benefits



Key DfE Technology – No Cadmium Fasteners



- **Traditional Aircraft Use Thousands of Steel Fasteners with Cadmium Plating**
 - *Cadmium provides corrosion protection and lubricity*
 - *Exposes Maintenance Workers to Cadmium During Depainting Because They Grind the Old Coatings Off*
 - *Several Thousand Dollars per Year for PPE and Longer Grinding Time Due to Occupational Limits*
- **JSF Uses Titanium or Stainless Steel Fasteners**
 - **No Cadmium**
 - Except for Three Locations with no Drop-in Replacement (QAD, SFD, Gun)
 - **More Expensive Up-front But Less Life Cycle Cost**



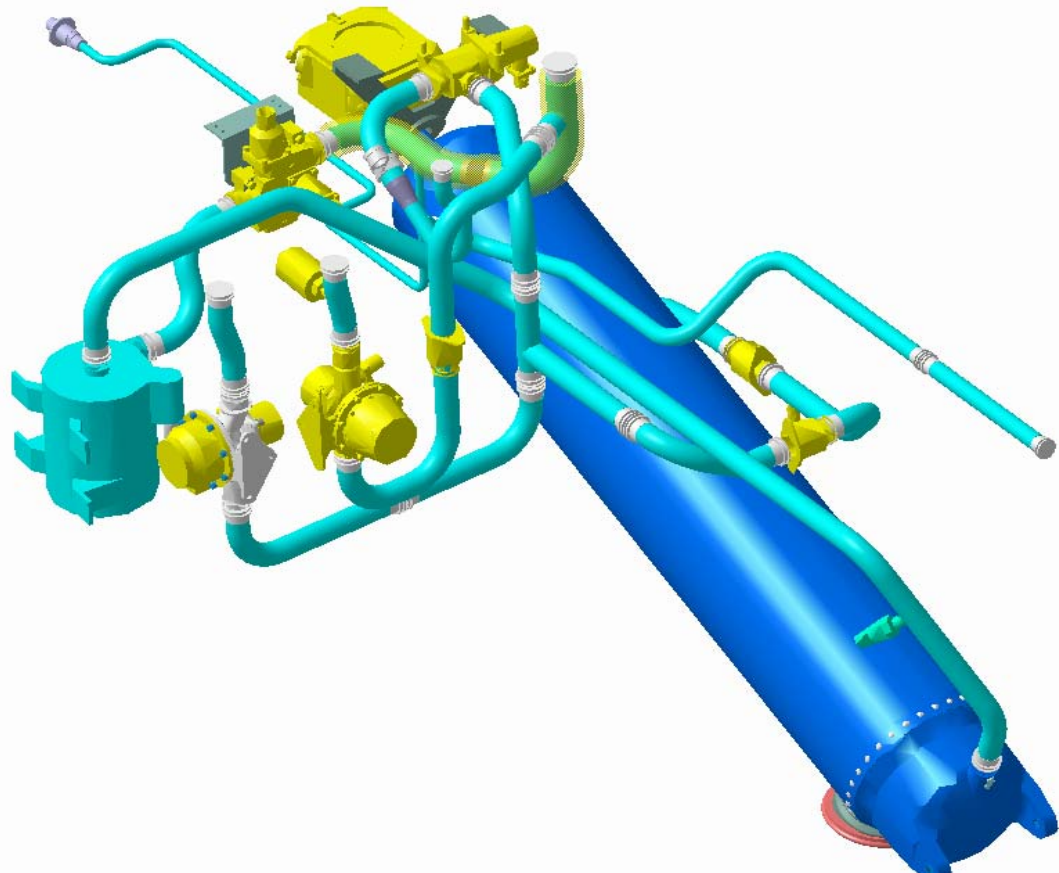
Reduces Up/Down Stream ESH Impact



Key DfE Technology - OBIGGS



- ***Traditional Military Aircraft Used Halon 1301 (ODC) to Provide Fire Protection to Fuel Tanks***
 - ***Empty Fuel Tank Volume Must be Filled with Inert Gas to Prevent Fire/Explosion from Bullets/Shrapnel***
- ***On-Board Inert Gas Generating System (OBIGGS) Replaced Halon 1301***
 - ***Filters out Oxygen from Ambient Air to Create Nitrogen Enriched Air Suitable for Fuel Tanks***
 - ***Military No Longer Required to Maintain Halon Stockpile for Wartime Fuel Tank Inerting***



No More Halon Stockpiles



Key DfE Technology - OBOGS

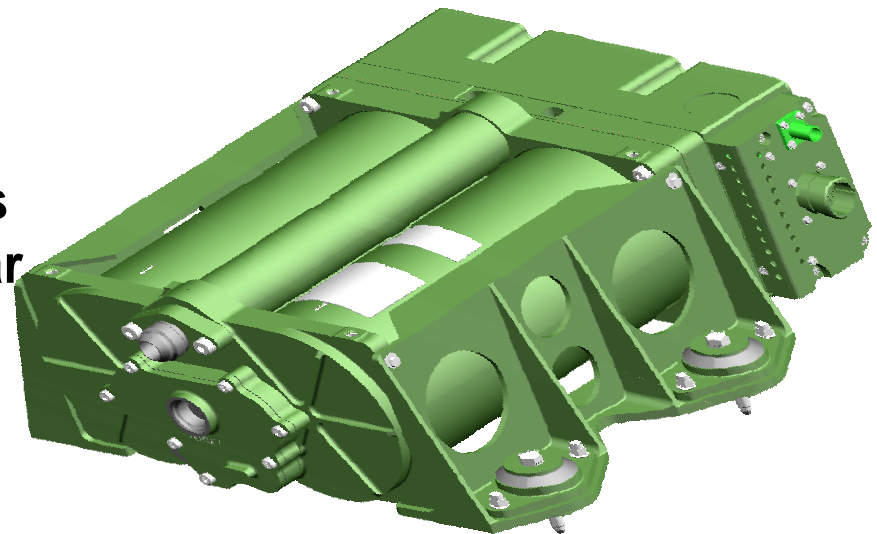


- ***Traditional Aircraft Carried the Pilots Oxygen Supply in Liquid Oxygen Tanks***

- ***Liquid Oxygen will Trigger Rapid Combustion of Any Dirt or Contaminates in the Supply System***
- ***Supply System Must Be Perfectly Clean***
- ***Best Cleaning Solutions Freon CFC-113 and HCFC-141b***

- ***On-Board Oxygen Generating System Replaced Liquid Oxygen***

- ***Produces Oxygen-Rich Breathing Gas From Engine Bleed Air Using Molecular Sieve Technology***
- ***No Exotic Cleaning Solutions***
- ***Military No Longer Required to Stockpile Freon for Oxygen System Cleaning***



No More Freon Stockpiles

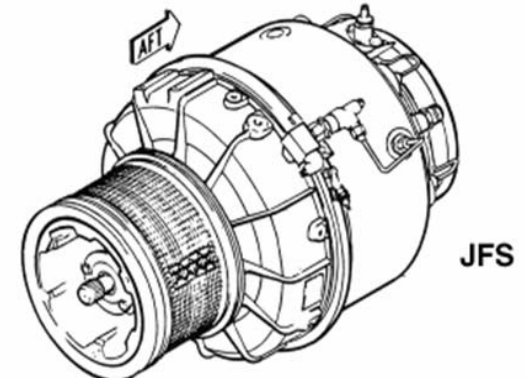


Key DfE Technology - IPP



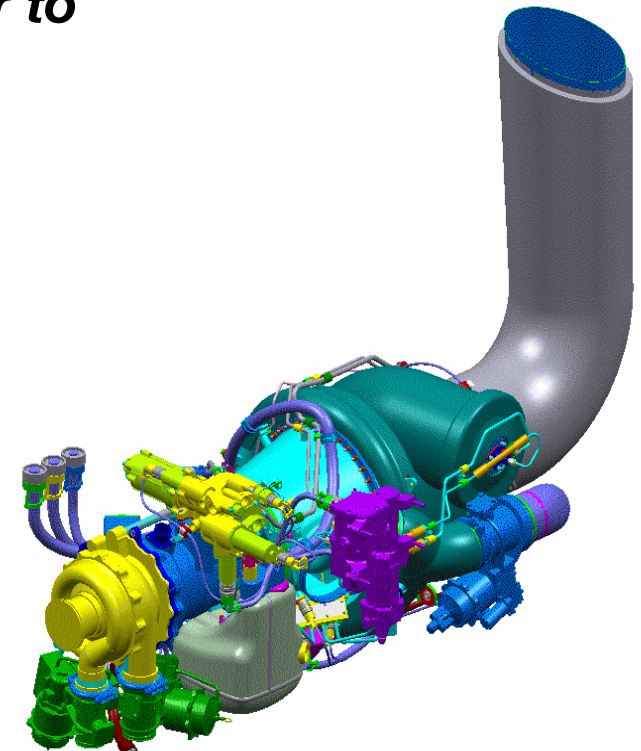
- **Traditional Military Aircraft Contain An Emergency Power Generation System to Restart Failed Engine at Altitude**

- **Some Systems Like F-16s Used Hydrazine**
- **Unstable, Toxic, Dangerous Fluid Produces Gas to Turn a Turbine and Generate Enough Power to Restart Engine**



- **Integrated Power Package (IPP) Replaces Hydrazine System**

- **Small Turbine Engine Integrated with Other Vehicle Cooling/Heating Systems**
- **Basically a Small Jet Engine**
- **Easy to Start/Stop, No Hydrazine, No Leaks**



No More Hydrazine Hazards



Key DfE Technology – Electric Actuators

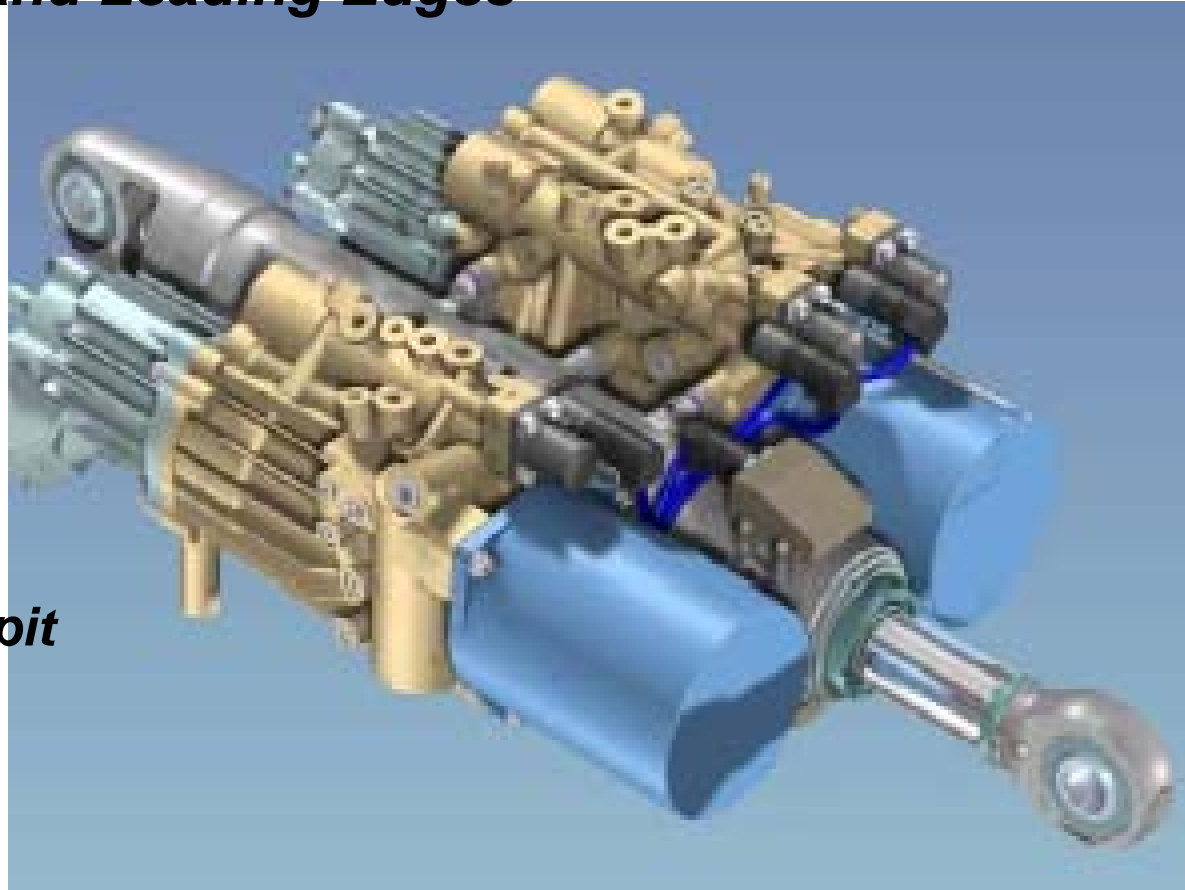


- ***Traditional Aircraft Use High Pressure Hydraulic Systems to Move Control Surfaces Like Flaps and Leading Edges***

- ***Frequent Maintenance***
- ***Spill Control and Clean Up***
- ***Filter Disposal***

- ***F-35 Developed Electro-Hydrostatic Actuators to Replace Hydraulics***

- ***Electric Control from Cockpit***
- ***Very Small Quantity of Hydraulic Fluid***
 - ***Low Pressure***
- ***Lifetime Sealed Unit***
 - ***No Maintenance Required***



Avoids Hydraulic Leaks and Clean Up



Key DfE Technology - HVOF

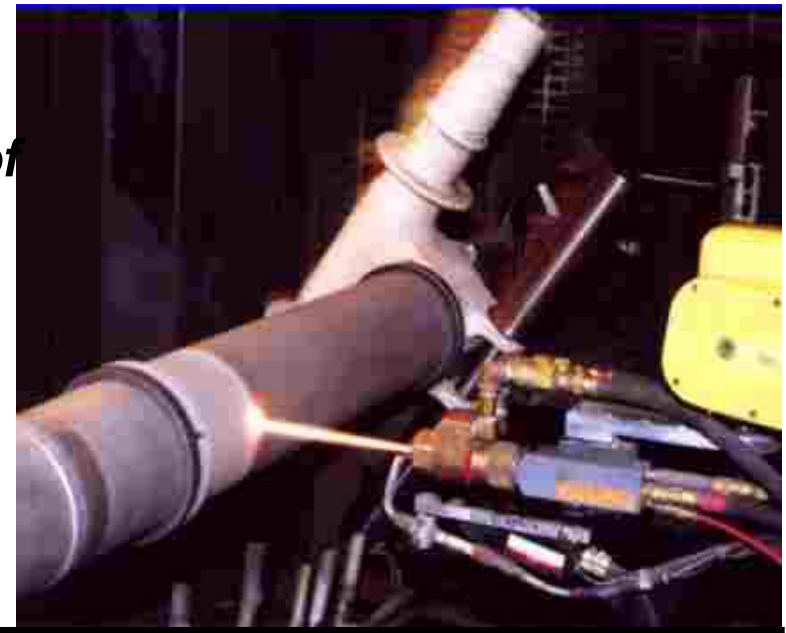


- **Traditional Aircraft Landing Gear and Other High Wear Surfaces were Chrome Plated**

- **Chrome Plating Bath Environmental Liability**
- **High Life Cycle Cost:**
 - **Requires Stripping/Replating every 3-5 Years**
 - **Military Services Must Have Plating Facilities**
 - **Replating Takes 2-3 Months**
 - **Requires Large Quantities of Spares**

- **High Velocity Oxygenated Fuel (HVOF) Technology**

- **High Velocity High Temperature Stream of Powder Shot Onto Part Surface Forming Hard Impervious Wear-Resistant Coating**
- **Long Life – Minimal Maintenance**
- **Ultra-Smooth Superfinish Extends Life From Seals That Rub Against HVOF Coating**
- **Standard Coating for All JSF Actuators, Wear Surfaces, Landing Gear**



No More Chrome Plating

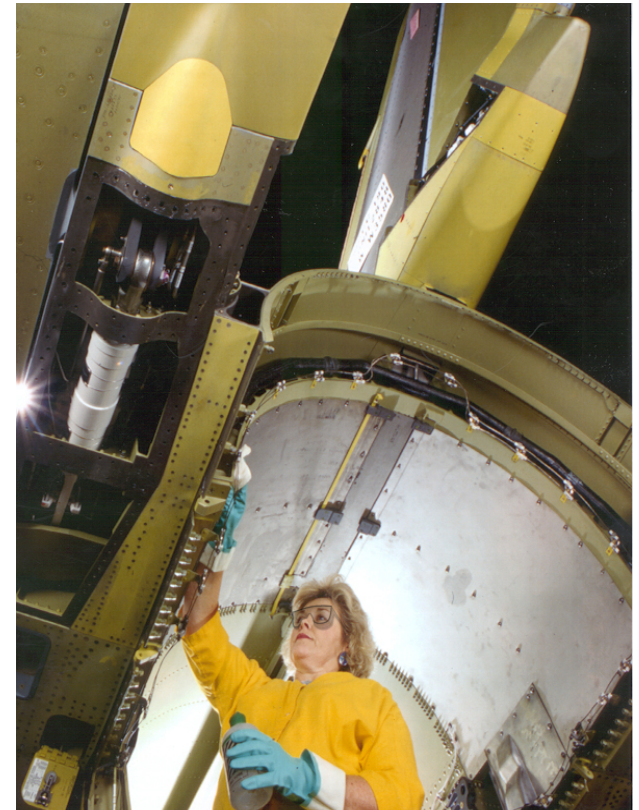


Key DfE Technology – ODC Free Manufacturing



- ***Traditional Aircraft Fabrication Aids, Sealants, and Cleaning Solutions Often ODC-Based***
 - ***Good Cleanliness and Efficient Product Delivery***

- ***LM Replaced All ODC-Containing Products in 1995***
- ***No Class I/II ODCs Allowed on F-35 to Date***



No More Ozone Depletion



In Work DfE Projects



- **Many Different Projects Underway Domestically and Internationally**
- **Eliminate Chrome**
- **Eliminate Cadmium**
- **Improve Maintainability**



Key DfE Technology Non-Chrome Primer



- **Approved Deft 44GN098 as F-35 Structural Primer**
 - *B-1 Effectivity (First STOVL)*
 - *Fully Implemented on Airframe by B-2*
 - Implementation on System Suppliers Voluntary to Avoid Costs
- **LM Aero and Northrop Grumman Running Four Batch Verification**
- **Galvanic Corrosion Testing In Progress**
- **Additional Compatibility with Exterior Finishes and Materials**
- **Potential Use as Flexible Primer**
- **Landing Gear 300M/A100 Steel Sacrificial Coating**
 - *Verified 6000 Hours Scribed Neutral Salt Fog with no Corrosion*
- **Qualified to LMA-MR003 Primer Specification**
 - *Equivalent to Mil-PRF-85582*
- **NAVAIR Recently Completed Qualification to Mil-PRF-85582**



Deft Non-Chrome Primer Corrosion Testing



2000 Hours Neutral Salt Fog Chromated Conversion Coated 2024 Aluminum

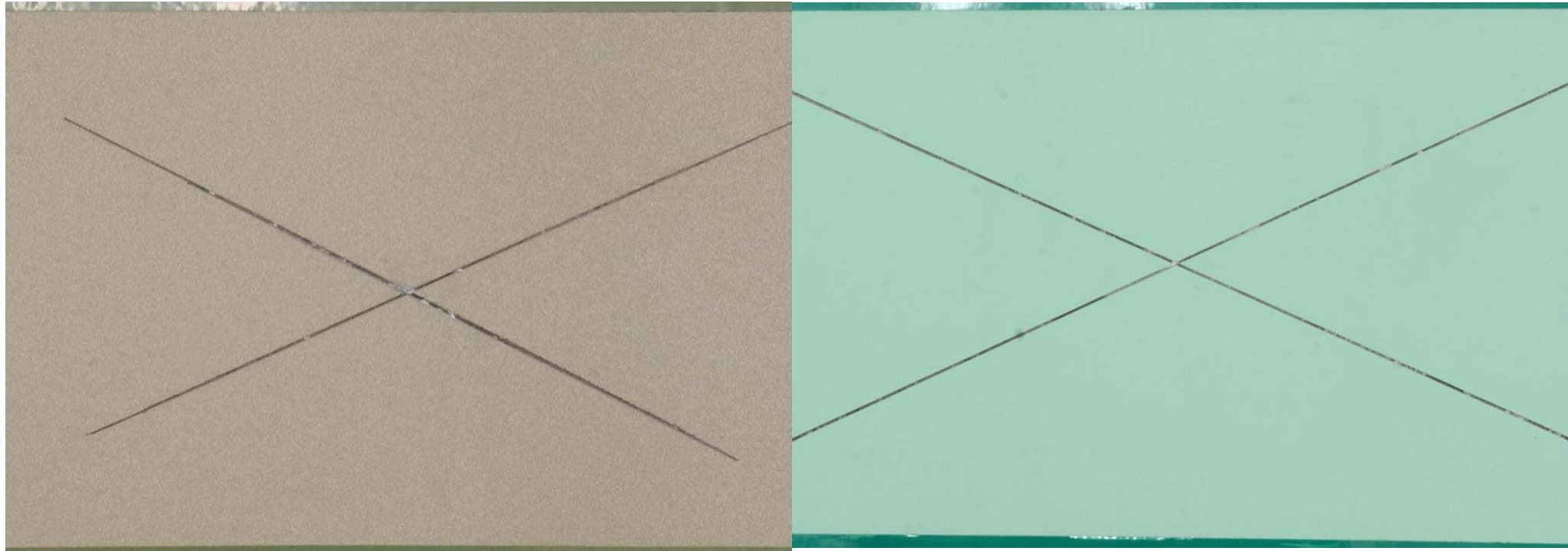




Deft Non-Chrome Primer Corrosion Testing



4000 Hours Neutral Salt Fog Chromated Conversion Coated 2024 Aluminum

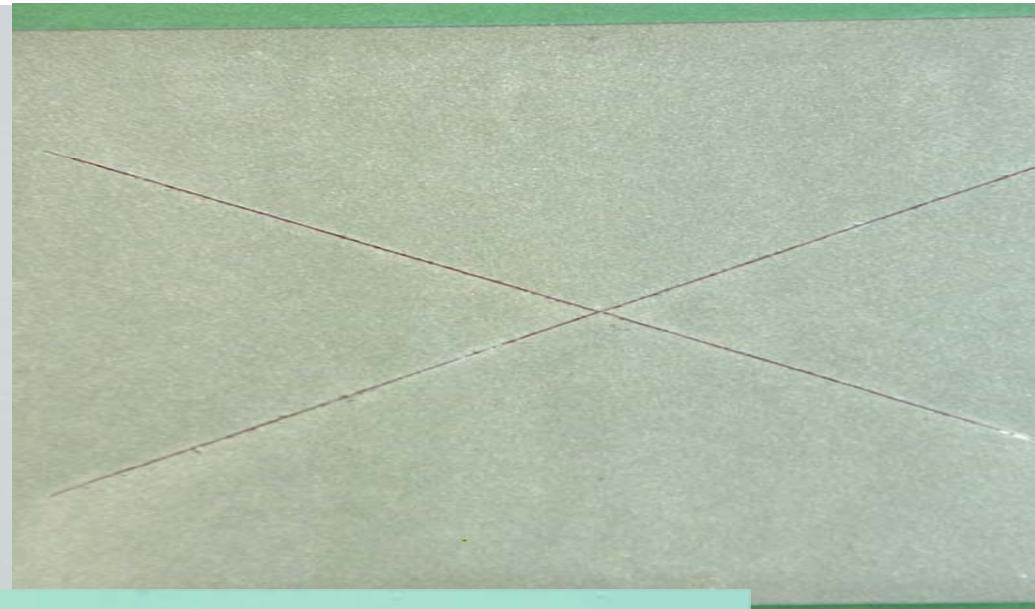




Deft Non-Chrome Primer Corrosion Testing



500 Hours SO₂ Salt Fog
Thin Film Sulfuric Acid Acid 2024 Aluminum





Field Exposure Evaluations



Daytona Beach Exposure



On-Board CVN USS Stennis In Indian Ocean





More Field Exposures



***Air Force C-130 Hatches
Special Mission Aircraft at
Antarctic Base –
Coated May 2004***





Other Non Chrome Primers



- **White Structural Primer to Eliminate Two Coat System**
 - *Replaces Typical Primer/White Urethane Topcoat*
- **Fuel Tank**
 - *Deft Adopting New Corrosion Inhibition Package for Structural Primer for Fuel Tank Coating*
 - *F-35 Program Office-Sponsored Small Business Innovative Research Project*
 - Down-select to Two Vendors
- **Flexible Primer**
 - *Current Baseline Deft 09Y010 But Evaluating 44GN098*
- **Conversion Coating**
 - *LMAero FW Evaluating Options*
- **Adhesive Bonding Primer**
 - *3M (EW5000-AS) and Cytec (BR6747-NC) Partially Qualified*
- **Adhesion Promoters**
 - *Replace PR182/AC160 with Waterborne PR188/AC-135*
- **Rain Erosion (Trivalent Chrome Colorant)**
 - *Two Vendors Developing Non-Tri Versions*



Key DfE Technology – Cadmium Plated Connectors



- ***Traditional Aircraft Power and Signal Connectors are Cadmium/Nickel Plated Aluminum***

- ***Dirty Cadmium Plating Operations***
- ***Limited Life on Aircraft Carriers***
- ***Soft Cadmium Rubs Off Connector***



- ***Alumiplate™ Qualified as Cadmium Replacement***

- ***Environmentally Friendly Application***
- ***Better Corrosion Protection out to 336 Hours in SO₂ Salt Fog***

- ***Almost All F-35 Connectors Switched to Composites***

- ***Working Alumiplate™ as Conductivity Coating for Composite Connectors***



Improved Performance Less ESH Impact

SO₂ Salt Fog Results



Figure 6.1.11 Ni/Cd connector after 336 hours in SO₂-salt-fog



Figure 6.1.5 TTH after 336 hours in SO₂-salt fog



Figure 6.1.6 Corrosion resistant stainless steel after 336 hours in SO₂-salt fog



Figure 6.1.9 Dull Ni composite after 336 hours in SO₂-salt fog



Figure 6.1.10 Bright Ni composite after 336 hours in SO₂-salt fog



Figure 6.1.3 Bright Zn/Ni after 336 hours in SO₂-salt fog



Figure 6.1.4 Dull Zn/Ni after 336 hours in SO₂-salt fog

subje



Alumiplate™ Results



Figure 6.5.1 Cannon Alumiplate connector with chemfilm after 338 hours in SO₂-salt fog



Figure 6.5.2 Cannon Alumiplate connector with clear coating after 338 hours in SO₂-salt fog



Connectors Released And Available



Amphenol® Cadmium Free Connectors With Electroplated High Purity Aluminum Finish Provide Superior Corrosion Resistance and Electrical Performance Under the Harshest Environmental Conditions



Now available in MIL-DTL-38999 Series III Aluminum or Composite
And MIL-DTL-5015 Series III (MS3450-3459) shell styles

Amphenol® connectors with the AlumiPlate® Electroplated High Purity Aluminum finish outperform all other Cadmium alternatives in terms of Corrosion Resistance, Electrical Conductivity, Galvanic Compatibility and other end use environments such as Salt, Sulphur Dioxide, De-icing Fluids and Lightning Strikes.

When tested, Amphenol® connectors with the MIL-DTL-83488D pure aluminum electroplated coating provide Cadmium-Free :

- ✓ Corrosion resistance up to 1000 hours in ASTM B117 salt spray testing
- ✓ Corrosion resistance up to 336 hours in ASTM G85, Appendix 4 Sulphur Dioxide testing
- ✓ Durability per MIL-DTL-38999K - 500 cycles mate/unmate for aluminum components, 1500 cycles on composite components.
- ✓ Durability per MIL-DTL-5015H Series III - 100 cycles mate/unmate for aluminum components.
- ✓ Shell-to-Shell conductivity values which meet or out perform Nickel and Cadmium finishes both before and after environmental testing
- ✓ Superior galvanic compatibility with mating materials

Amphenol® connectors with the AlumiPlate® Electroplated High Purity Aluminum finish have been tested by Lockheed Martin Aeronautics Company and are being considered as the leading choice for the F-35 Joint Strike Fighter program.

For further information on Amphenol® connectors with the Electroplated High Purity Aluminum finish please contact us at:

Amphenol Corporation

40-60 Delaware Avenue, Sidney NY 13838-1395

Phone: 807-583-5011 or 800-678-0141 Fax: 807-583-5157

Website: www.amphenol-aerospace.com

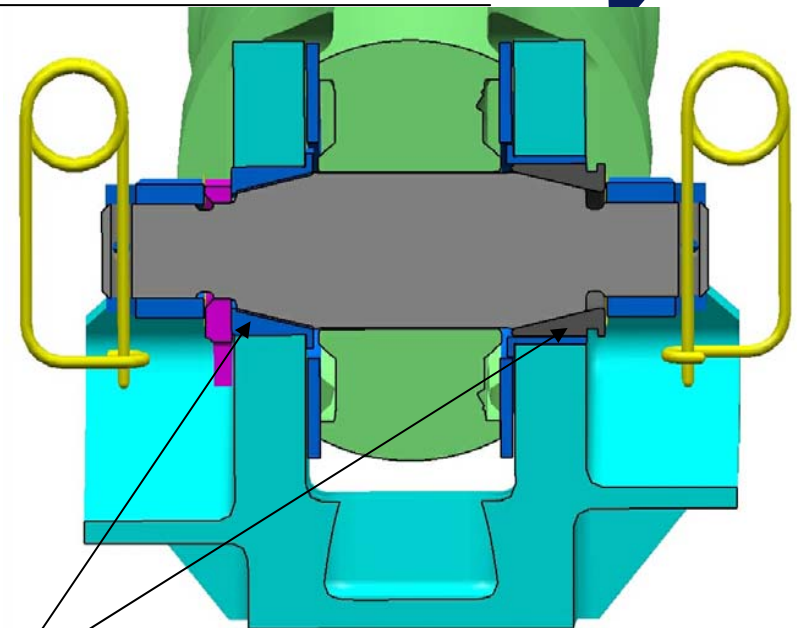
Amphenol



Key DfE Technology - Copper-Beryllium Bushing Replacement



- Copper-Beryllium (Cu-Be) Bushings Added to LMAero Restricted Materials List February 2004
 - *F-35 Technical Mgmt Concurred with Action Plan to Identify Locations and Develop Alternative Material Where Feasible*
- Typically Used for Flight Control Actuators and Other High Load Environments
 - *350+ Specific Locations*
 - *Switched to Other Materials for Many Applications*

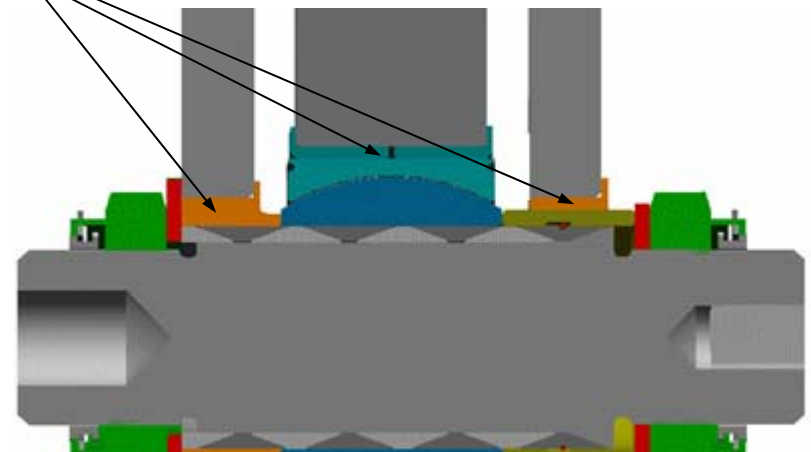


Horiz Tail Actuator

Cu-Be Bush

*Main Landing
Gear
OutBoard
Trunnion Fitting*

*Horiz Tail
Inboard Hinge*



Rapidly Qualify/Implement New Materials



Bushing Replacement Lab Testing



- **F-35 Evaluation of Alternative Materials**
 - *ToughMet, Nitronic 50/60, 304/HBN, SBIR Developed, etc..*
 - *Phase 1 Completed Tensile, Compression, Bearing, and Shear*
 - *Phase 2 Completed Wear and Galling*
 - *Phase 3 Completed Elevated Temp Tensile*
 - *Phase 4 Completed SCC and Salt Fog exposure*
 - *All F-35 Bushings <2.5"Ø Switched to Cold Worked Nitronic 60*
 - *Phase 5 test plan Evaluating Installation Issues*
- **ASC PP3010 FY05-06 Funding**
 - *Subscale Testing and Implementation*
- **Materials Affordability Initiative (MAI)**
 - *25/75 Contractor/Government Cost Share with LM/Boeing/BrushWellman*
 - *Phase III Advanced Screening and Toughmet "S" Basis Generation*
 - *Phase IV Toughmet "A/B" Basis Generation, Fatigue and Fracture, Installation*
 - *Phase V Implementation Studies*





Key DfE Technology - Corrosion Detection

- **F-35 Needs Low Budget Device to Solve Several Issues**
 - *Corrosion Detection, Locate OML Panel Edges and Fasteners, Detect Fluid Leaks, Inspect Composite Material Beneath Several Coating Layers, Verify Coating Thickness*
- **Existing Phase II SBIR Developed Microwave Corrosion Detection Device**
- **F-35 JPO ESH Sponsored Phase II Extension and Phase III Commercialization**
 - *LMAero F-35 Generating Reqmts*
- **P2 Benefit – Reduce Scheduled (non-necessary strip/repaint cycles) Coating Maintenance, Minimize Coating Damage During Event Maintenance**



Avoid ESH Impact of Needless Coating Rework



Future ESTCP Cooperation



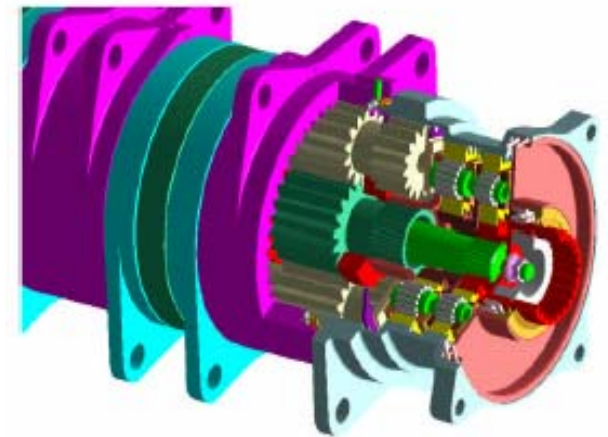
How F-35 and ESTCP Can Continue to Work Together and Expand Work to Enhance Value



Key DfE Technology - Cadmium Plating



- ***Traditional Aircraft Steel Parts Protected From Corrosion by Cadmium Plating***
- ***Several Alternative Technologies Under Development***
 - ***Alumiplate™***
 - ***New High Temp Metal Coatings***
- ***ESTCP Funded S-53 High Strength Stainless Steel Dem/Val Program on F-35 RGAs***
 - ***Risk Reduction Phase Underway by Fabricating One RGA 'Set' and Fatigue Testing***
 - ***LMAero/BAES Studying Corrosion Performance Enhancements***
 - ***Full Demonstration Starts 2007***



Rotary Gear Actuators

Eliminate Cadmium Plating



Cadmium Plating Irrelevant with S-53?



- **Ultimate Solution is New High Strength Stainless Steel**
 - ***No Secondary Plating***
 - ***Ferium S-53 from Questek Once Class A Allowables Complete***
 - ***Strength of 300M (225Ksi YS and 285Ksi UTS) With 15-5PH Stainless Steel Corrosion Resistance***
 - ***Fracture Toughness 85 ksi-inch^{1/2} Versus 300M 50 ksi-inch^{1/2}***
 - ***Stress Corrosion Cracking Strength >50 Versus <10***
 - ***3 Heat Qualification Underway for ESTCP Program***
 - ***Ogden ALC Intends to Adopt for All AF Landing Gears Where Possible to Avoid Cadmium Plating***
 - ***Goodrich/MOOG/Curtis Wright Monitoring Product for F-35 Use and Participating in RGA Demonstration***

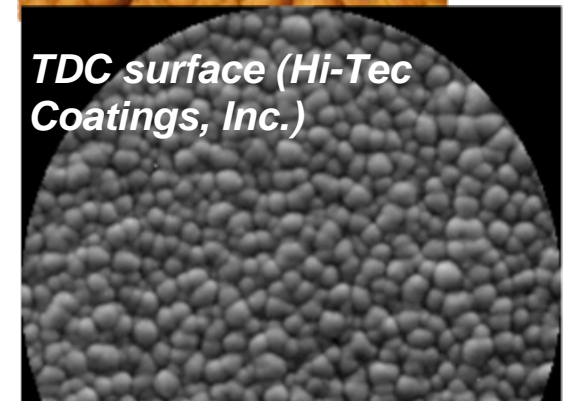
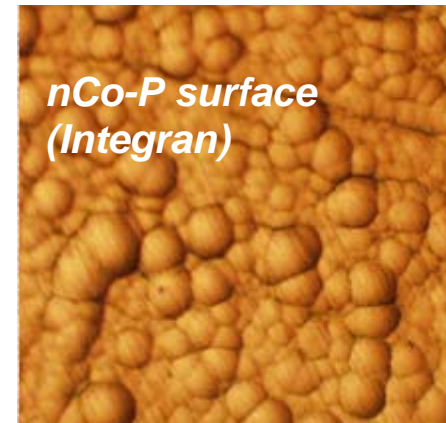
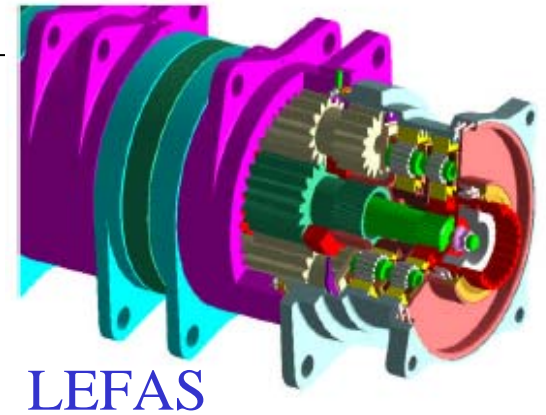
Elimination is Ultimate Solution



Key DfE Technology - Nodular Thin Dense Chrome (TDC)



- TDC used for corrosion and wear resistance – numerous callouts on gears, bearings, actuator IDs
 - Nodular Surface Provides Lubricity*
- F-35 Sponsored ESTCP Follow on for Nanophase Cobalt-Phosphorus
 - Will Screen Process Development Samples*
 - F-35 Vendors Moog/Curtis Wright/Smiths Participating*



	TDC	nCo-P
Thickness	0.0001-0.0006"	0.0001->0.020"
Hardness	900-1,100HV	650-1,000HV
Morphology	Nodular	Nodular
Coeff friction	~60% EHC	~60% EHC
Roughness	4-10μ" Ra	<4μ" Ra

nCo-P Promising TDC Alternative



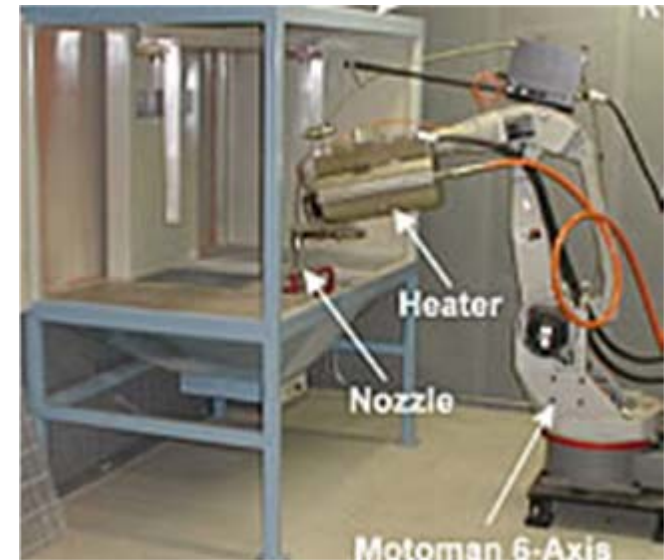
Key DfE Technology – Supersonic Particle Deposition



- Current In-Field Coating Repair of Cadmium/IVD-Alum Coated Surfaces is Brush Cadmium or Other Chromated Products Like Sermatel™
- Cold Spray Emerging Technology
- More Effective Magnesium Corrosion Repair Needed
- 2004 Navy SBIR IVD Repair Evaluating Several Cold Spray Techniques
 - NADEP Cherry Point
 - Purchased Inovati Kinetic Metallization™ System
- F-35 Funded DSTO (Australia) and AFRL
 - Leverage off NRL ESTCP
 - Provide Effect of Defects Panels
 - In Cooperation with
 - Hamilton Sundstrand (ESG Mag Generator Housing, Pump Housing, more)
 - Honeywell (PTMS with Mag Housing)



Brush Cadmium



K-Tech Cold Spray Equipment

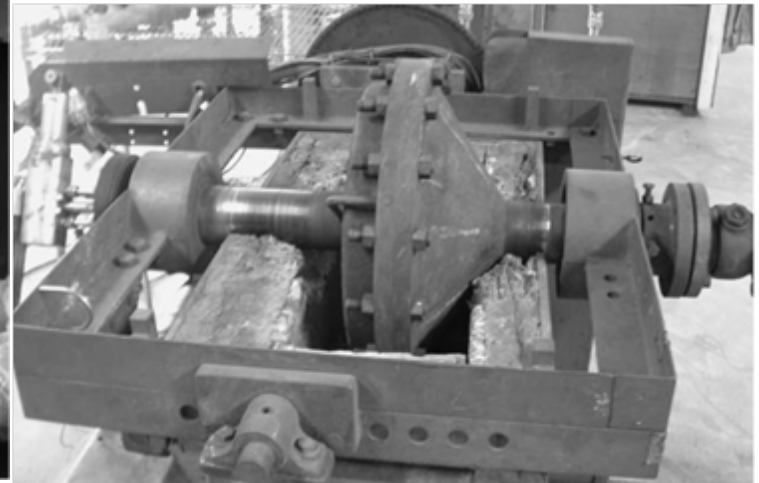
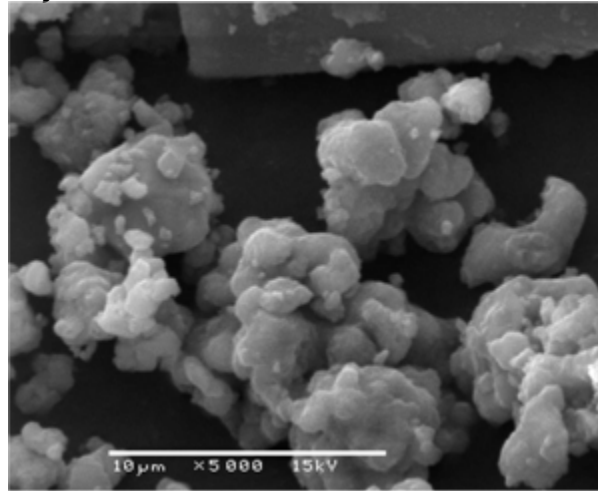
May Require Several Repair Options



Key DfE Technology - Material Disposal



- CDRL A001 Requires Disposal Plan
- No Available Methods for Composites/Low Observable Materials
- Need Recycling Alternative with Beneficial Reuse to Avoid RCRA HazWaste Designation for Disposal
- Phase II Air Force SBIR LO Coating Destruction
 - Phase I Fluidized Bed Reactor Concept Demonstrated Complete Breakdown of Materials and Conversion to Calcium Carbonate
- F-35 Participating in Phase II
 - *Provide Materials, Lab Verification of Destruction*
- ESTCP Scale Up Assistance?



Eliminate Composite Disposal Uncertainty



Key DfE Technology - Gap Fillers



- LO Aircraft Require Gap Fillers Between Exterior Panels
- Typically Nickel Filled
- Maintainer Exposure Issue During Panel R&R Due to Sanding/Grinding Filler
- F-35 Studying Alternative Materials
 - *Northrop Grumman Awarded AFMC P2 R&D Program*
 - Non-nickel Alternatives
 - *Other Internal R&D Projects*
- If Successful Alternative Found, Can ESTCP Assist with Cross-Program Qualification/Implementation?
 - *Unique Program Qualification Requirements will Drive Cost*

Improved Performance Less ESH Impact



Summary



- ***F-35 Largest DoD Weapon System Acquisition Program***
- ***Replaces Several Legacy Aircraft Worldwide***
- ***Operates Under Comprehensive ESH Management and Hazmat Control***
- ***Conducts Aggressive Pollution Prevention and Material Substitution Activities Focusing On Life Cycle Cost Reductions***
- ***Integrates Partner Country Requirements into Program***



DfE/Sustainability Objective



Minimize ESH Impacts on Four Program Tenants